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EQUIPMENT DESIGN/IMPLEMENTATION OF AIR SOURCE HEAT PUMP

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Tiivistelmä

Opinnäytetyön tavoitteena oli suunnitella ja toteuttaa ilmalämpöpumpun laitteisto energiatekniikan laboratorioon. Tämän työhön kuuluu suunnittelu ja lisäantureiden asentaminen ilmalämpöpumppuun, automatisointi ja käyttöliittymän tekeminen.

Työn aluksi tehtiin PI-kaavio ja etsittiin sopivia lisämittareita, sekä PLC-logiikan ja logiikan komponentteja. Kun kaikki anturit oli asennettu ja liitetty S7-1200-logiikkaan, kehitettiin HMI-käyttöliittymä. Termodynaamisen prosessin piirtäminen tehtiin OpenOffice Calc -ohjelmassa, joka vastaanottaa mittaukset FS gateway -protokollamuuntimen käyttöön. Entalpian laskennassa käytetiin ilmaista CoolProp.dll-tiedostoa tietojen siirtoon taulukkolaskentaan. Lopuksi tarkasteltiin lämpötilakorjaukset pinta-antureista.

Insinöörityön tuloksena tehtiin uusi laitteisto lämpöpumppputekniikan opiskelua varten.
Tietojen keruu ja termodynaamisen prosessin piirtäminen ph kaaviossa ovat täysin automaattisia. Lisäksi esiteltiin esimerkkejä laboratoriotöistä.

Asiasanat
Ilmalämpöpumppu, termodynaaminen prosessi, entalpia, CoolProp.dll, COP

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Abstract

The objective of this thesis was to design new equipment for studying heat pump technology in the energy technology laboratory of Kymenlaakso University of Applied Sciences. The study includes planning and implementation of laboratory air-conditioning sensory interface (air source heat pump) and data automation system design.

Implementation began from the design of the flow chart and providing of suitable additional sensors, PLC and its components. After the sensors had been mounted and connected to the PLC, an HMI interface was developed. The OpenOffice Calc program, connected to the Wonderware Intouch via the FS gateway protocol converter, was used for plotting the thermodynamic cycle on the P-H diagram. For enthalpy calculation, the CoolProp library freeware was used. Finally, the correction issue of the surface temperature sensors was solved.

As a result of the thesis, new equipment for studying heat pump technology was created. Data collection, process chart and thermodynamic cycle plotting are fully automated. In addition, examples of laboratory work is presented in this thesis.

Keywords
air source heat pump, thermodynamic process, enthalpy, CoolProp.dll, COP

CONTENTS

1 INTRODUCTION

I have been studying Energy Engineering at Kymenlaakso University of Applied Sciences since 2012. The degree program gives competences in environmentally friendly and economical energy production and in innovative energy technology and engineering. Laboratory work comprises an important part of the studies. It is necessary for acquiring practical and research skills.

In summer 2015 the Energy Technology Laboratory acquired new equipment for studying heat pump technology, as well as energy-efficient heat pumps.

The purpose of this thesis is to plan and connect additional sensors to the air source heat pump, and to design the automation of data collection and a convenient tool for laboratory work. As a result, the cooling/heating process will be shown with all collected data, and the thermodynamic process of the air source heat pump will be plotted on the pressure-enthalpy diagram.

2 AIR SOURCE HEAT PUMP THEORY

2.1 Principles of Operation

A heat pump is a device that can move heat from a low temperature to a high temperature. This means that the same piece of equipment can be used to remove heat from a space (cooling) at one end while at the same time adding heat to another space (heating) [1]. Because heat pumps move heat rather than generate heat, they can be considered the most efficient form of electric heat. The most common sources for heat pump are outdoor air, ground (bedrock or soil) and water (ground, sea and river).

2.1.1 Heat Pump Components

Heat pumps consist of a condenser, an expansion device, an evaporator and a compressor.

The evaporator absorbs heat into the system. The refrigerant heats and boils to vapor.

The compressor is considered the heart of the refrigeration system. It pumps heat through the system in the form of a heat-laden refrigerant.

The condenser rejects heat from the refrigeration system, while the refrigerant releases heat and returns to a liquid state.

The expansion device is the counterpart of the compressor. It returns high-pressure liquid refrigerant adiabatically to the low-temperature, low-pressure liquid that enters the evaporator.

2.1.2 Pressure/Enthalpy Diagram

The pressure-enthalpy diagram or P-H diagram describes the relationship of pressure and enthalpy of a select refrigerant. They allow the HVAC and refrigeration engineers to quickly identify the state, temperature, pressure, enthalpy, specific volume and entropy of a refrigerant at a given point.

On the P-H diagram, pressure is indicated on the y-axis and enthalpy is indicated on the x-axis (Figure 1). Enthalpy describes how much heat a substance contains with respect to an accepted reference point. A horseshoe-shaped curve is called the saturation curve. The left-hand curve is the saturated liquid curve. If heat is added, the refrigerant will start changing state to a vapor; if heat is removed, the liquid will be subcooled. The right-hand curve is the saturated vapor curve. The saturated liquid and vapor curves touch at the top. This is called the critical temperature or critical pressure. Above this point, the refrigerant will not condense. [2, 61]

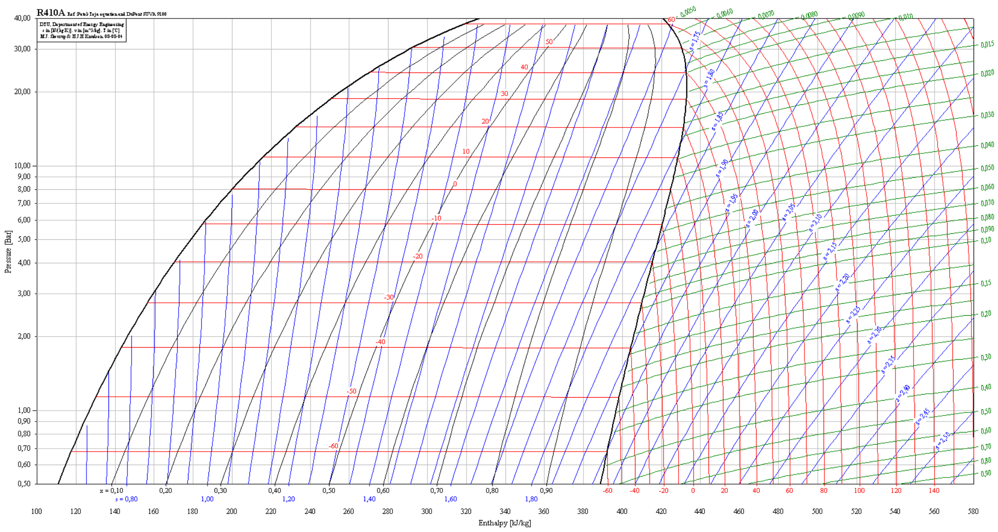

Figure 1. P-H diagram [3]

2.1.3 Liquid, Vapor and Mix Regions

The curves break up the diagram into three regions. The left one is a liquid region. In this region, there are vertical temperature lines, which increase as enthalpy is increased.

The middle one is a liquid-vapor mix region. In this region, the P-H diagram shows horizontal temperature lines, which indicate constant temperature. There are also upward sloping curves which indicate quality (0-100%).

The right one is a vapor region. In this region, there are vertical temperature lines, which increase as enthalpy is increased. In addition, there are lines of constant entropy, which are also important. Entropy is the measure of the amount of disorder in the system. [4]

2.1.4 Real Heating Cycle on the P-H Diagram.

Figure 2 illustrates a real heating cycle. The curve 4-1 is a compressor work. The vapor refrigerant is compressed on the line from 5.4 Bar to 25.4 Bar and the heat content increases by 63 kJ/kg. The refrigerant leaves the compressor at point 1 at 87 °C and enters the condenser. The refrigerant is now cooled and condensed from the saturated vapor line to the saturated liquid line. The temperature decreases to 25 °C and heat content loses 233 kJ/kg. Point 3 describes the expansion valve output. There are 73% liquid and 27% vapor at temperature -8 °C and pressure 6 Bar. It then travels through the evaporator (3-4) and at point 4 the refrigerant in vapor state with 5 °C of superheat. In the evaporator the heat content increases from 253 kJ/kg to 423 kJ/kg.

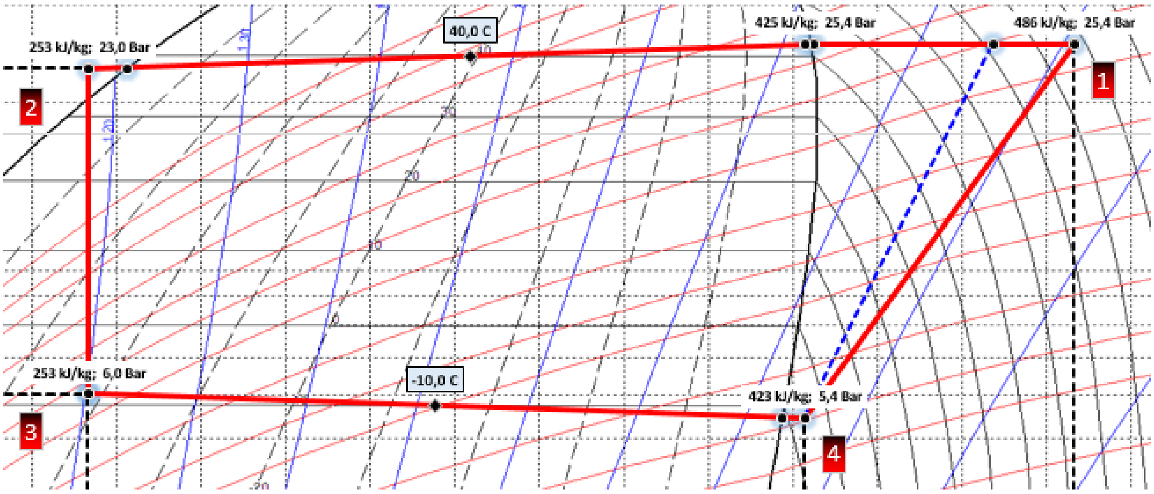

Figure 2. Real heating cycle

2.2 Efficiency of Heat Pumps

In the comparison of heat pumps, two factors – COP and SCOP (SEER) – are normally used. The COP, or Coefficient of Performance, describes the efficiency of the heat pump and is defined as the ratio of useful heat movement to the amount of energy input of a heat pump. The COP of air source heat pump depends on the outside air temperature, therefore the same heat pumps have different performance in the northern and the southern climates. Manufacturers publish operating values based on the standard measurements (EN 14511). According to this standard COP is measured at +7 °C outdoor temperature [5, 6].

2.2.1 $COP_{heating}$

The COP for a heat pump system operating in the heating mode is given by the following formula:

$$COP_{heating} = \frac{Total\ Heat\ of\ Rejection}{Heat\ of\ Compression}$$

[2, 1260]

From the values shown in Figure 2, the net heating effect is 233 kJ/kg (486 kJ/kg-253 kJ/kg) and the heat of compression is 63 kJ/kg (486 kJ/kg – 423 kJ/kg). The COP coefficient is equal 4 (233 kJ/kg : 63 kJ/kg is 4). It can be regarded as 400% efficient. This calculation of the COP takes into account only the enthalpy change of the compressor. The fan’s electrical consumption and the motor’s efficiency make actual COP lower than the theoretical.

A high COP occurs only during higher outdoor winter temperatures. It is still economical to operate when the temperature of the outdoor air remains above – 20 °C [2, 1260]. In the coldest period, an extra heating system is needed to cover the total heating demand.

2.2.2 $COP_{cooling}$ /ERR

The efficiency of a heat pump as the cooling generator is measured by the ratio between heat taken from indoor and external work needed for operation

$$COP_{cooling} = \frac{Net\ Refrigeration\ Effect}{Heat\ of\ Compression}$$

[2, 1259]

For the system shown in Figure 2, the $COP_{cooling}$ is 2.7 (170 kJ/kg : 63 kJ/kg is 2.7). This example shows that the $COP_{heating}$ is higher than the $COP_{cooling}$ (4>2.7) of the same heat pump system.

2.2.3 Carnot Efficiency

The maximum theoretical efficiency is often referred to as the COP_{carnot}, which is calculated according to the following equation:

$$COP_{carnot\ heat} = \frac{T_{hot}}{T_{hot} - T_{cold}}$$

$[6, 217]$

where

T_{col} : describes the temperature of the cooling reservoir, [°C]

T_{hot} : describes the temperature of the heat reservoir, [°C]

For example if T_{col} is +7°C and T_{hot} according to Figure 2 is 87°C then $COP_{carnot\ heat}$ = 360K / 80K = 4.5.

2.2.4 SCOP and SEER

SCOP, or seasonal coefficient of performance, also takes into account the temperature fluctuations. SCOP is therefore an expression of how efficient a specific heat pump will be for a given heating demand profile. The calculation method of SCOP for heat pumps is described in the European Standard EN 14825.

SEER, or seasonal energy efficiency ratio, is the same as SCOP, but for cooling application.

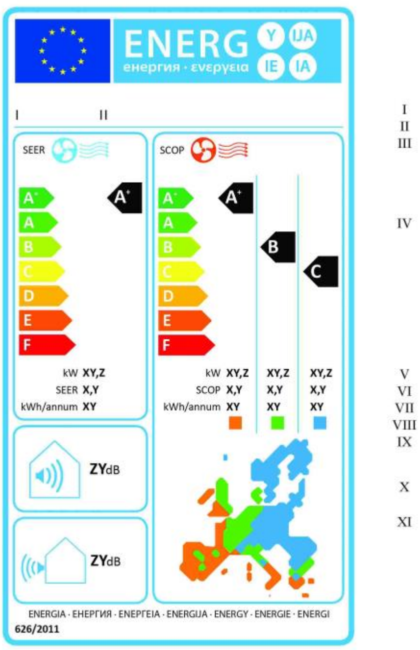

Figure 3. European energy label for air-to-air heat pumps from 1 Jan. 2015 [7]

The current energy label for air conditioners refers to the seasonal coefficient of performance and the seasonal energy efficiency ratio, to express the energy efficiency of heat pumps. The figure 3 [7], illustrates the energy label, which was introduced on 1 January 2015. The label shows the design capacity in kW, the energy efficiency of heating (SCOP) and the annual energy consumption in the three different climate zones as well as cooling (SEER).

A number of energy classes are based on SCOP values, and the SCOP is related to the heating season ‘average’. Table 1 shows energy efficiency classes for air conditioners according to Directive 2010/30/EU [7]

Energy Efficiency Class	**SEER**	**SCOP**
A+++	SEER ≥ 8,50	SCOP ≥ 5,10
A++	6,10 ≤ SEER < 8,50	4,60 ≤ SCOP < 5,10
A+	5,60 ≤ SEER < 6,10	4,00 ≤ SCOP < 4,60
A	5,10 ≤ SEER < 5,60	3,40 ≤ SCOP < 4,00
B	4,60 ≤ SEER < 5,10	3,10 ≤ SCOP < 3,40
C	4,10 ≤ SEER < 4,60	2,80 ≤ SCOP < 3,10
D	3,60 ≤ SEER < 4,10	2,50 ≤ SCOP < 2,80
E	3,10 ≤ SEER < 3,60	2,20 ≤ SCOP < 2,50
F	2,60 ≤ SEER < 3,10	1,90 ≤ SCOP < 2,20
G	SEER < 2,60	SCOP < 1,90

Table 1. Energy efficiency classes for air conditioners [7]

3 PROJECT DESCRIPTION

Universities need a convenient tool for studying the air source heat pump. With all of it, that is written above, the students may calculate the values of COP and ERR, place the state point in the P-H diagram as well as watch and study which way the heat pumpes in practice.

This implementation includes design, installation and connection of additional sensors into air source heat pump, mounting program logic controller and programming the user interface.

3.1 Flow Charts

Figure 4 shows the flow charts. For project implementation, additional 4 pressure and 8 temperature sensors must be installed.

Additional sensors for the inside unit:

- two pressure and two temperature sensors are installed as close as possible to the evaporator inlet and outlet pipeline
- one sensor at the outer edge of the circular fan of the cooling unit
- one sensor measures the indoor temperature.

Additional sensors for the outside unit:

- two pressure and two temperature sensors are installed as close as possible to the condenser inlet and outlet pipeline
- one temperature sensor on the pipeline after the compressor
- one sensor measures outdoor temperature.

PI-DIAGRAM

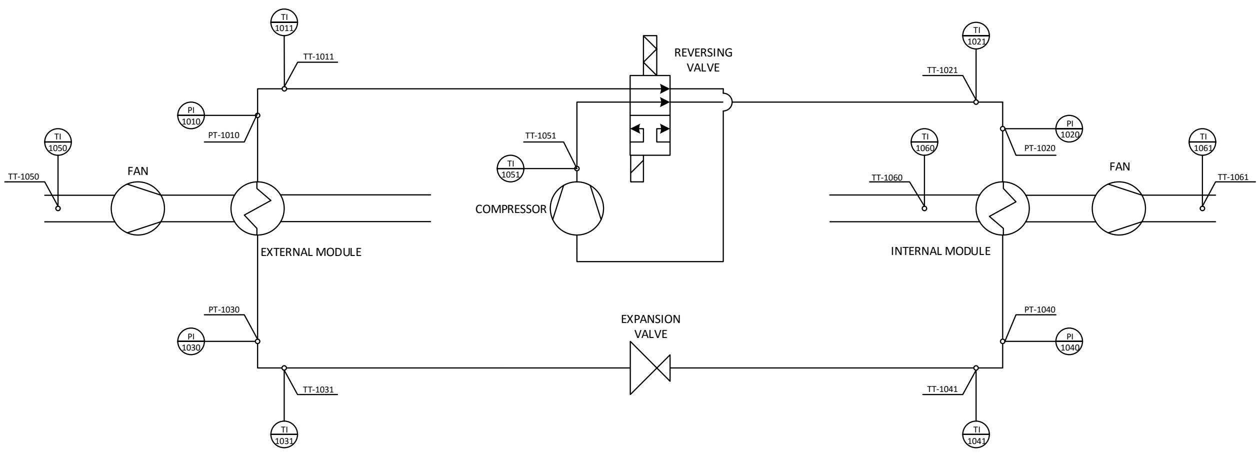

Figure 4. Flow charts

4 COMPONENTS

4.1 Air Source Heat Pump

The main component of the study is a Daikin FTXL25J2V1B air source heat pump that has the following specifications: [8]

Cooling capacity	min/nom/max	kW	1.2/2.5/5.1
Heating capacity	min/nom/max	kW	1.0/4.5/6.5
ERR			3.38
COP			3.78
SEER			5.1
SCOP			4.04
Refrigerant type			R410A

Table 2. Daikin FTXL25J2V1B specification

4.2 Pressure Sensors

The pressure sensors are needed to determine the control points on the P-H diagrams. In addition, they are showing pressure losses in the system. For the purpose of this study, the sensors Gems 3100B0060G05E000 with M12 x 1P electrical connector have been selected. The pressure measurement range is 0-60 Bar (Relative).

To mount the sensors, four T shaped junctions are soldered into the condenser/evaporator inlet/outlet pipelines. As shown in Figure 5, the pressure port is connected through the valve to the T shaped fitting.

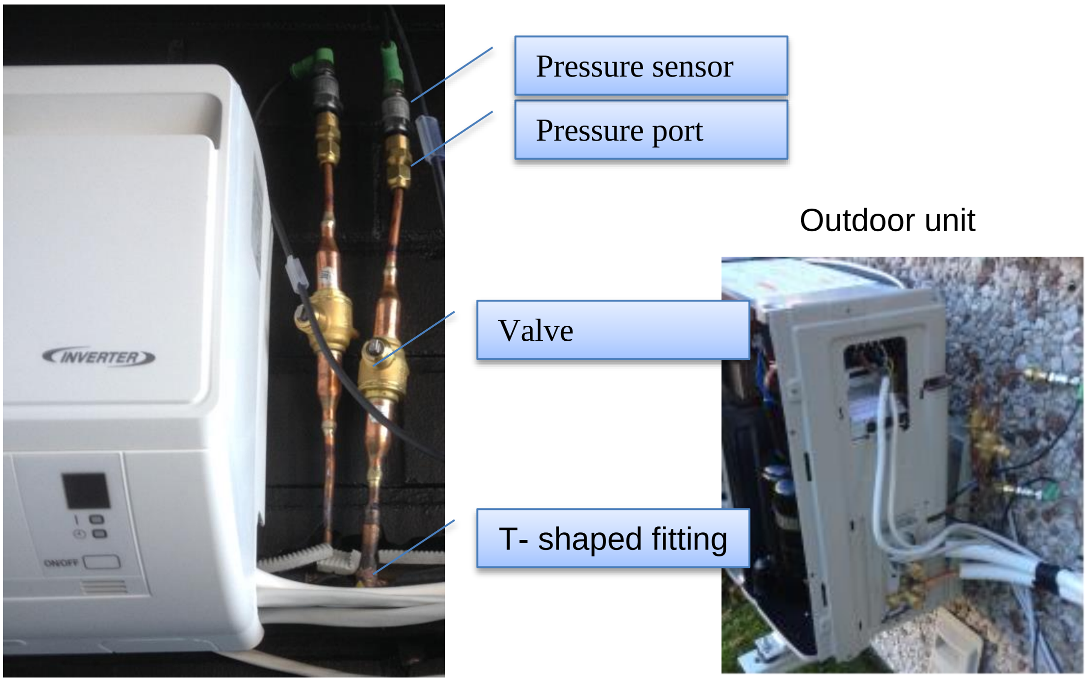

Figure 5. Connecting pressure sensors

The outdoor unit sensors are placed outside the housing, because inside there is no space for them. Sensors provide signal 4-20mA and use a 2-wire connection.

The company that was engaged in the installation and repair of the refrigerator performs this work.

4.3 Temperature Sensors PT-100

Figure 6 shows a low cost surface-mounted RTD (resistance temperature detector) that is installed onto a surface for temperature measurement. Five sensors are installed on the pipeline. Conductive paste is placed between the housing and

Figure 6. RTD temperature sensor

surface to improve the thermal response. The other 3 sensors are used for measuring indoor and outdoor temperatures.

The temperature range of sensors is -50 °C to 500 °C. For this study, a 4-wire configuration is used.

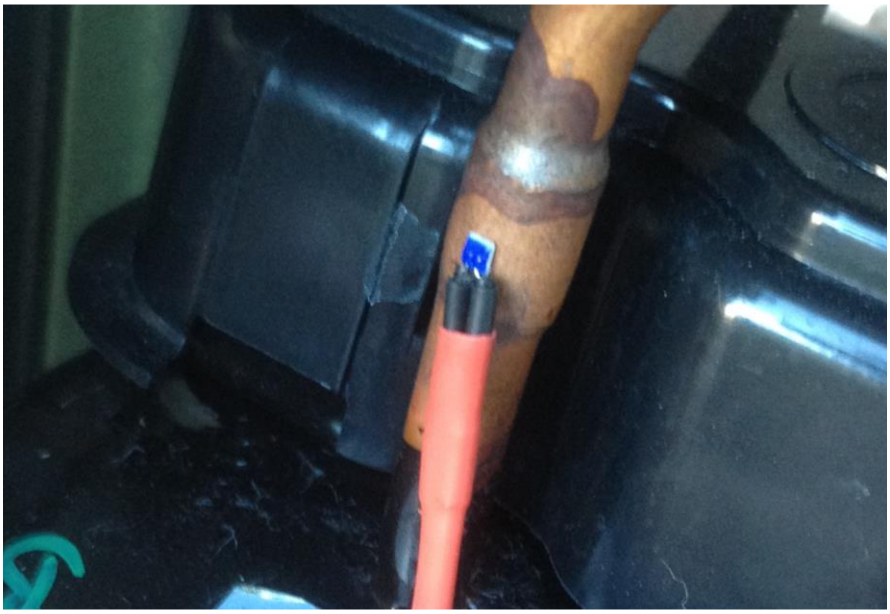

Figure 7. Mounting RTD sensor

4.4 Current Sensor

The T201 (Figure 8) is an isolated, contactless loop powered current transducer. The sensor is used to assess all power consumption of the air source heat pump (indoor and outdoor unit together).

Figure 8. Current transmitter [9]

4.5 PLC

For the purposes of this study, the Siemens SIMATIC S7-1200 CPU 1212C COMPACT modular controller was selected, with 4 digital outputs, 2 digital inputs and an integrated Ethernet port. The Ethernet port is used for communication and getting data to a personal computer. In addition, the controller system is expanded by two signal modules. The RTD module SM 1231 with 8 ports gets data from eight PT-100 temperature sensors. The SM

1231 analog input module is needed to obtain information from four pressure sensors and one current sensor.

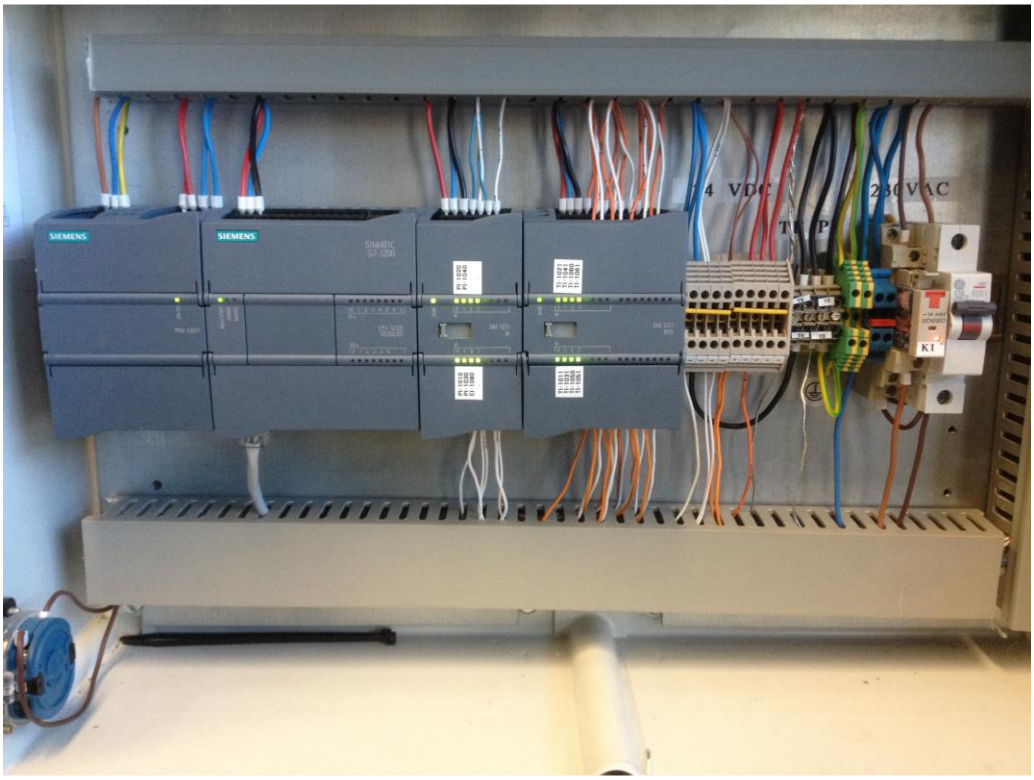

Figure 9. PLC with additional modules

The current supply PM 1207 is suited for controllers S7-1200 and works as external supply of input/output sensors.

5 REALIZATION

5.1 Equipment Connection

Figure 10 shows the connection schema. The PLC controller and the operator’s PC are located in the same room and are connected by an ethernet cable. All PLC components are placed in a special box (box 1) near the indoor unit. In addition, terminal box 2 is near the outdoor unit. The 24 pair cable links the boxes. All indoor sensors are attached to the PLC directly, and the outdoor sensors are connected through the terminal box.

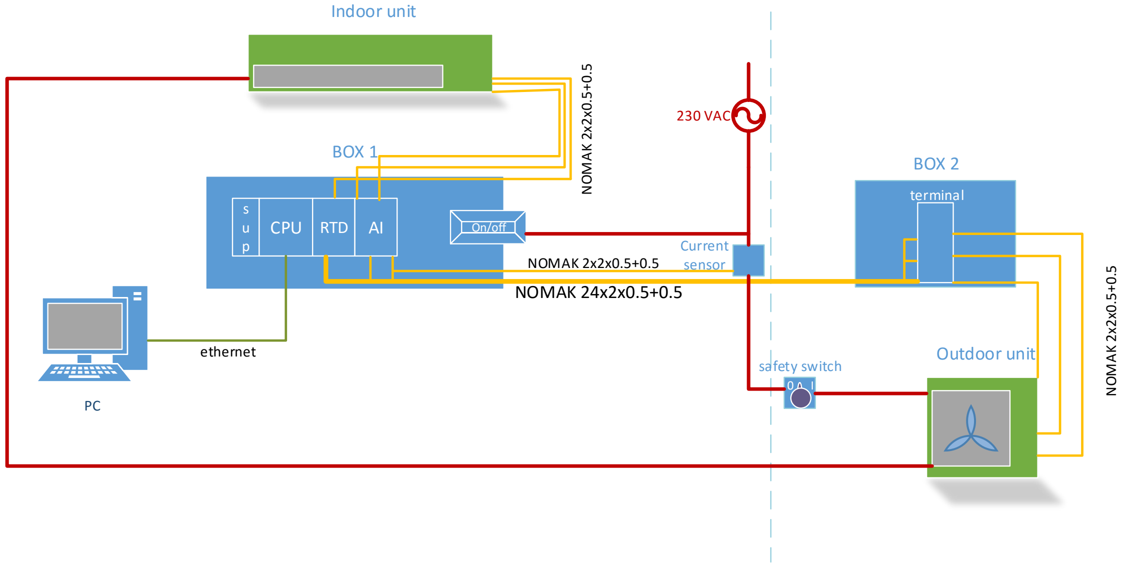

Figure 10. Connection schema

5.2 SCADA (supervisory control and data acquisition)

A Wonderware InTouch platform is used to provide the operator interface, logging of historical data, and putting data to the OpenOffice Calc. This platform has a library of Device Integration solutions, which include DAServers (Data Access Servers), FactorySuite (FS) Gateway, Device Integration (DI) Objects, Proxy Objects, I/O Servers, Tag Creators and other. [10]

5.2.1 Communications

In the study, two servers are used: DAServer for communication to the program logic controller and FS Gateway for communication with OpenOffice Calc. Those servers are configured in an ArchestrA System Management Console. All servers have standard settings according to their documentation.

5.2.1.1 Problems Communicating with FSGateway

FSGateway.exe must be started as an application by running C:\Program Files\Wonderware\DAServer\FSGateway\Bin\FSGateway.exe, not as a service. Otherwise, it returns communication failures under the newer MS Operating Systems such as Windows7. The newer OS always runs all Services in Session 0, and each logged-in user is assigned a different Session ID. Running Calc and FSGateway in two different sessions is equivalent to operating in a networked environment. This requires NetDDE. However, NetDDE is obsolete, and no longer available. [11]

To resolve this problem FSGateway is started as an Application.

5.2.2 Human Machine Interface

HMI is drawn in MS Visio. Two pictures (the heating and cooling process) are placed on Intouch as a background, and the tags with information from the sensors are placed over them. A script that compares the pressure between tags PI-1010 and PI-1020 changes the layout of the background pictures. When PI-1010 is higher than PI-1020, the program shows a picture with the cooling process, otherwise the script shows the heating process. At the same time, labels are changed and tags, which the OpenOffice Calc reads, are prepared. Figure 11 shows HMI for heating process.

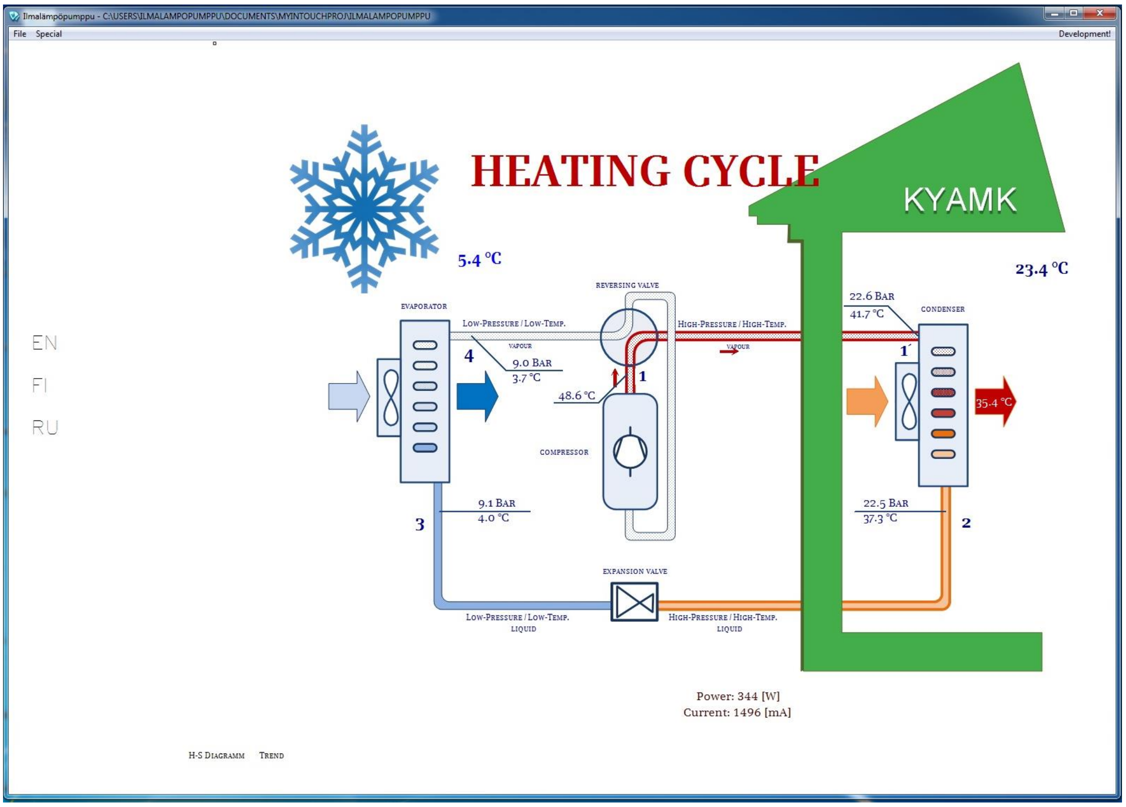

Figure 4. HMI Heating Cycle

In addition, two windows are designed, one of which is used for the refrigerant P-H diagram and other one for history trends.

5.2.3 P-H Diagram and Thermodynamic Cycle

The P-H diagram describes the relationship between the pressure and enthalpy of a select refrigerant. Pressure is obtained directly from the pressure sensors but enthalpy depends on refrigerant thermodynamic properties such as pressure, temperature, state, and quality of vapor. Thermodynamic properties, tables and the equation of refrigerant r410a are presented on the international portal for the refrigeration and a/c industry (http://www.refripro.eu/fic_bdd/fluides_pdf_fichier/11630956210_SOLKANE_410.pdf) [12]. In addition, there are several libraries and programs which can calculate the enthalpy. In this study, the free CoolProp C++ library is used.

CoolProp is an open-source database of fluid and humid air properties, formulated based on the most accurate formulations in open literature. It has been validated against the most accurate data available from the relevant references. [13]

Due to the fact that Intouch (v.14) does not support API call and does not have a convenient tool for plotting graphs, this part of the project is implemented in the free OpenOffice Calc application.

The file enthalpy.ods (OpenOffice Calc) consists of two sheets. On one of them data tables are located, which contain coordinates of the process points: pressure, enthalpy and supporting data for the calculation. The other one consists of a chart.

5.2.3.1 Chart

The picture of the P-H diagram is used as background for the line chart. X and Y axis are selected so that they coincide with the axes on the background. For this purpose, the scale of y-axis is logarithmic.

5.2.3.2 Data Table

Two parameters, pressure and temperature, come from Intouch via the FSGateway server. These cells consists of the following function:

=DDE("fsgateway";"ilmalampopumppu";"P3_2")

Where

DDE = name of function
“fsgateway” = name of a server
“ilmalampopumppu” = name of InTouch project
“P3_2” = intouch project’s tagname (item)

The CoolProp library is used for the calculation of enthalpy. The downloaded DLL is placed in c:\CoolProp. In addition, a module with the following script is added in the main file:

```

Private Declare Function PropsSI_private Lib "C:\CoolProp\CoolProp.dll" Alias "_PropsSI@32" (ByVal ReturnValue As String, ByVal Name1 As String, ByVal Value1 As Double, ByVal Name2 As String, ByVal Value2 As Double, ByVal Ref As String) As Double

Public Function PropsSI(ByVal ReturnValue As String, ByVal Name1 As String, ByVal Value1 As Double, ByVal Name2 As String, ByVal Value2 As Double, ByVal Ref As String) As Double
    'Get the single character forms
    PropsSI = PropsSI_private(Byval ReturnValue,Byval  Name1,Byval  Value1,Byval  Name2,Byval  Value2,Byval  Ref)
End Function

Public Function Clc
    Thiscomponent.calculateall()
End Function
```

Figure 5. Additional script

This script allows using the PropsSI function in cells like standard functions.

After that, the next formula calculates enthalpy of superheated vapor or sub cooled liquid:

=PROPSSI("H";"T";273,15+C6;"P";B6*100000;"R410a")/1000

Where

PROPSSI = name of function

H = the first parameter indicates what this function returns. H – enthalpy [J/kg]

T = name of second parameter, T – Temperature

273,15+C6 = data of second parameter [K]

P = name of third parameter, P – Pressure

B6*100000 = data of third parameter [Pa]

"R410a" = the name of refrigerant

Point 3 is in the mix region and there is no information about the quality of vapor. Without this, it is impossible to calculate the enthalpy. Therefore, enthalpy from point 2 is used for point 3. Figure 13 shows the finished table on the worksheet.

D7 =PROPSSI("H";"T";273,15+C7;"P";B7*100000;"R410a")/1000

	A	B	C	D	E	F
1						
2						
3	R410A	Prosessitietö		Calculate		Category
4	Piste	P [Bar]	T [C]	h [kJ/kg]	s [kJ/(kg*C)]	
5	3	9,2 Bar	4,6 C	282 kJ/kg	1294,225311	[3] 9,2 Bar; 282kJ/kg
6	4	8,6 Bar	2,9 C	423 kJ/kg	1808,294472	[4] 8,6 Bar; 423kJ/kg
7	1	31,6 Bar	79,2 C	468 kJ/kg	1835,259435	[1] 31,6 Bar; 468kJ/kg
8	2	31,3 Bar	48,2 C	282 kJ/kg	1267,251338	[2] 31,3 Bar; 282kJ/kg
9	3	9,2 Bar	4,6 C	282 kJ/kg	1294,225311	[3] 9,2 Bar; 282kJ/kg

Figure 6. OpenOffice Calc, data worksheet

There are two lines with number 3 in the table. The first one is the starting point and the other one is the finishing point. It needs to draw full cycle of process, so diagrams shows the close cycle.

5.3 Sensor Correction

5.3.1 Temperature Sensor Correction

The copper pipeline inside the outdoor unit has no insulation, and therefore the outdoor temperature affects the surface temperature measurement. The greater the difference between the refrigerant temperature and outdoor temperature, the greater the error. The maximum temperature difference is at point 1(after compressor).

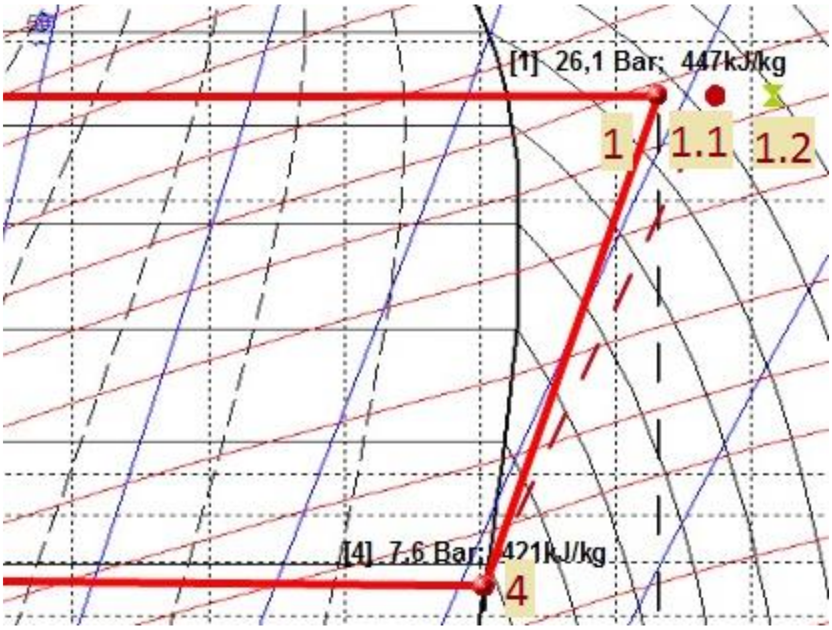

Figure 7. Experiment

On the figure 14, the dashed red curve 4-1.1 is the isentropic process or the process of compressing of ideal gas. Point 1 shows the measured temperature and point 1.2 is the theoretical temperature when the compressor isentropic efficiency is 80%. The difference between the measured and theoretical temperature is about 15°C (outdoor temperature 2°C).

Figure 15 shows heat transfer through a copper wall. Copper has very high thermal conductivity 400[W·m−1·K−1]. Thus, the temperature difference between T_2 and T_3 is so small that it is not considered.

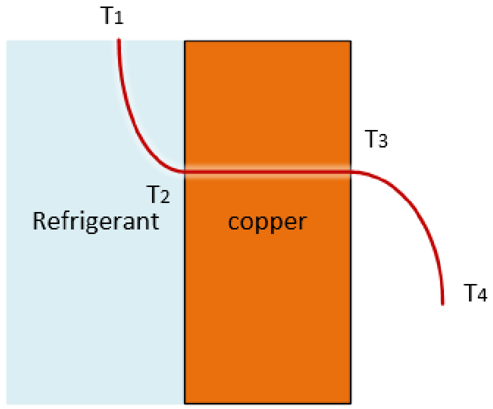

Figure 8. Heat transfer through a copper wall

The heat transfer rate (Q) can be calculated by the following equation [14]:

$Q = UA(T_1 - T_4)$

where

Q = heat transfer rate, [W]
A = heat transfer surface area, [m^2]
U = overall heat transfer coefficient, [W/m^2°C]
T_1 = refrigeration temperature, [°C]
T_2 = outdoor temperature, [°C].

In addition, the heat transfer rate can be calculated between points T_3 and T_4.

$Q = \alpha A(T_3 - T_4)$[14]

where

Q = heat transfer rate, [W]
A = heat transfer surface area, [m^2]
α = air heat transfer coefficient, [W/m^2°C]
T_1 = refrigeration temperature, [°C]
T_2 = outdoor temperature, [°C].

The following equations show the result of dividing one into another:

$$UT_1 - UT_4 = \alpha(T_3 - T_4)$$

$$T_1 = T_4 + \frac{\alpha}{U}(T_3 - T_4)$$

The temperature of the refrigerant depends on the coefficient k ($\frac{\alpha}{U}$), where air heat transfer coefficient (α) is constant because it depends on the airflow, and airflow in the outdoor unit is constant (H. Kuhling α= 5,6 + 4*W where W[m/s], airflow).

The following equation can be used to determine the U value.

$$\frac{1}{U} = \frac{1}{\alpha_{refr}} + \frac{1}{\alpha_{air}}$$

where

U = overall heat transfer coefficient, [W/m^2°C]
α_{refr} = convective refrigerant heat transfer coefficient, [W/m^2°C]
α_{air} = convective air heat transfer coefficient, [W/m^2°C]

After the compressor in point 1, condition of vapor is changed within a small range, therefore an assumption can be made that α_{refr} is constant. This means that U is constant and k is constant.

$$T_1 = T_4 + k(T_3 - T_4)$$

To determinate k, 15 experiments were performed with different conditionals and the average value was calculated. T_1 is the theoretical temperature when the compressor isentropic efficiency is 80%.

Date	T_4 out	T_3 surface	T_1 theoretical	P[Bar]	k	Comment
26.11.15	1,4	55,8	70,8	26,6	1,28	fun1
26.11.15	1,3	53,6	69,2	25,6	1,30	fun5
26.11.15	1,3	53,8	69,3	25,7	1,30	fun5
26.11.15	1,4	55,3	67,4	26,4	1,22	fun1
26.11.15	1,4	52,3	67,8	25,4	1,30	fun1
26.11.15	1,4	58	72	27,3	1,25	fun1
26.11.15	1,4	47,6	61	23	1,29	small temp in room settings
04.11.15	8,7	61,7	68,8	29,7	1,13	fun1

04.11.15	8,1	65,7	71,3	28,9	1,10	fun1
03.11.15	9	64	74,2	29,7	1,19	Fun 1
03.11.15	9	64	78	31,3	1,25	Fun 1
03.11.15	9,1	61,5	76,1	27,9	1,28	Fun 1
18.11.15	5,5	49,5	61	24,2	1,26	Fun 1
18.11.15	5,6	48,4	60,6	24	1,29	Fun 1
06.11.15	2	50,3	66,3	25	1,33	Fun 1
				Average k	**1,25**	

Table 3. 15 experiments

The refrigerant temperature T1 is corrected by formula:

$T1 = T_{outdoor} + 1,25 * (T_{surface} - T_{outdoor})$

Outdoor temperature sensors near the heat exchanger are not corrected because the temperature difference between the refrigerant and outdoor temperature is small. Indoor temperature sensors are not needed to be corrected, as they have good isolation.

5.3.2 Pressure Sensor Correction

The pressure scale of the P-H diagram is in absolute value, but sensors show relative pressure measures. To correct this, 1 Bar is added to the indicators.

6 SUMMARY

As result of this study, Kyamk Laboratory received new equipment for studying heat pump technology. Data collection and process chart plotting are fully automated. In addition, based on the project files, it was also created an enthalpy and COP calculator.

A larger issue in the study was the surface temperature sensor correction. The flow sensors allow calculating the Reynolds and Nusselt number and as a result the correction is more accurate. Using of the power sensor instead of using the current sensor gives more curtain result because it takes into account the cos φ. On the other hand, the received accuracy is exactly enough for understanding the operating principles of a heat pump, studying the thermodynamics cycle and conducting laboratory work, examples are showed in appendix 2.

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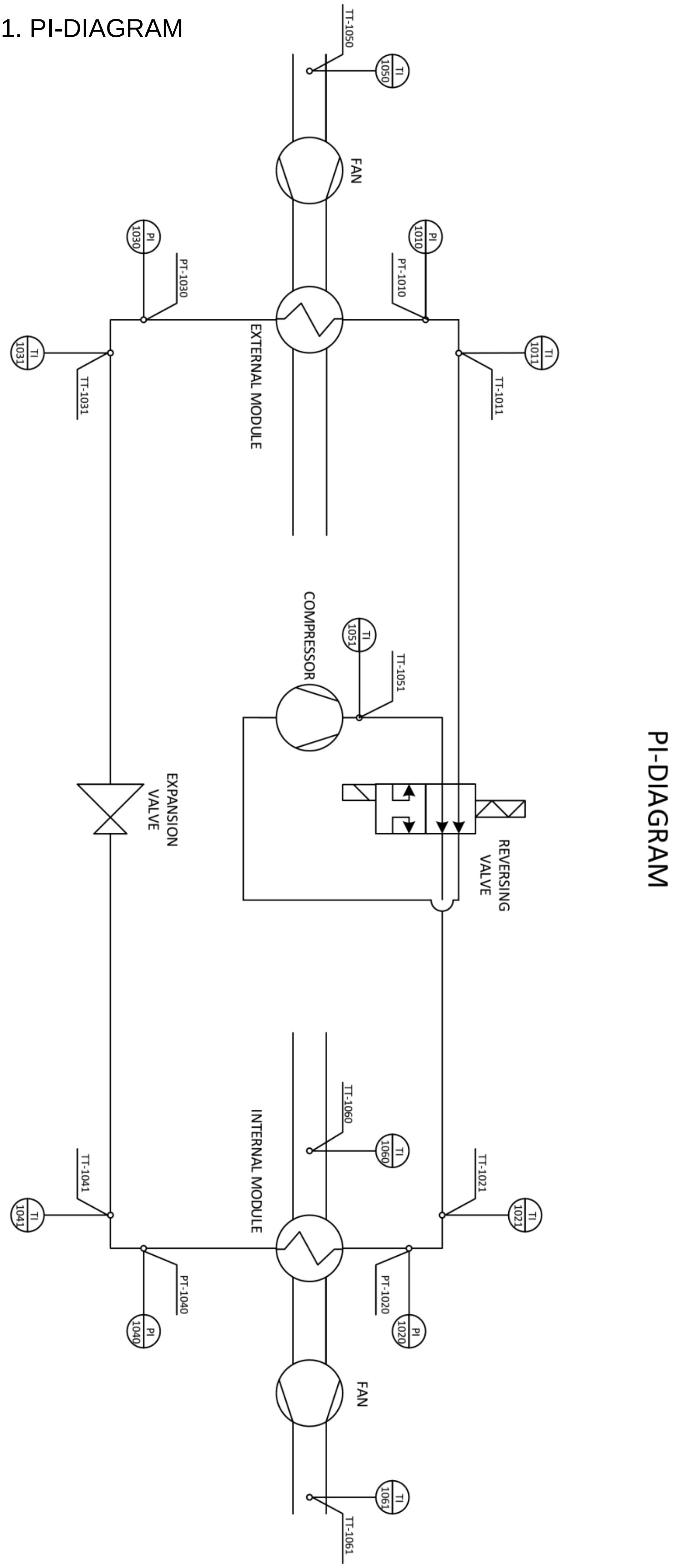
APPENDIX 1. PI-DIAGRAM



APPENDIX 2. EXAMPLES OF LABORATORY WORK

Exercise 1. P-H Diagram

Task 1

- Turn on the air-source heat pump in the heating mode and wait for a stable state (5-10 min)
- Put process points in the P-H Diagram and draw the thermodynamic process
- Mark compressor, condenser, evaporator and expansion valve works on the P-H diagram.

Task 2

- Calculate the coefficient of performance of the heat pump in the cooling and heating cycle. Are they the same? If not, why?
- Draw on the P-H diagram the compressor's isentropic work. Calculate the isentropic efficiency of the compressor.

Exercise 2. Thermodynamics work

- Turn on the air-source heat pump in the heating mode, choose the maximum speed of the fan and wait for a stable state (5-10 min).
- Open the "enthaply.ods" file, the thermodynamic cycle of the air-source heat pump is plotted on the "enthalpy R410a" sheet.
- Calculate mass flow of the refrigerant when the volume flow rate of air, which goes through the indoor unit, shows 200 m^3/h. The density of air at standard atmospheric pressure is presented in the following table:

Temperature C	Density kg/m3	Temperature C	Density kg/m3
-20	1.395	25	1.184
0	1.293	30	1.165
5	1.269	40	1.127
10	1.247	50	1.109
15	1.225	60	1.060
20	1.204	70	1.029